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# IGY BULLETIN

*A monthly survey by the U. S. National Committee for the International Geophysical Year. Established by and part of the National Academy of Sciences, the Committee is responsible for the U. S. International Geophysical Year program in which several hundred American scientists are participating and many public and private institutions are cooperating.*

## Oceanography Program: First Twelve Months

*The following report is based on material supplied by Gordon G. Lill, Head, Geophysics Branch, Office of Naval Research, Washington, D. C., Roger R. Revelle, Director, Scripps Institution of Oceanography, La Jolla, California, and other participants in the IGY Oceanography Program.*

### Deep Water Ship Operations

The IGY brought the element of international cooperation to the systematic study of the oceans. Single institutions and countries have lacked sufficient oceanographic vessels for large-scale, coordinated investigations. But in the IGY Deep Water Ship Program, over 20 countries are operating more than 80 ships in coordinated studies of the circulation and currents of the major ocean basins. Cruises vary from several hundred miles to 40,000 miles or more in length, from a few days for off-shore observations to as much as ten months for extended studies.

Five extensive cruises and several shorter ones have been completed in the US-IGY Program. Three long cruises were in progress at the end of the first twelve months of IGY and at least two others were scheduled for the summer of 1958. Because data reduction is usually performed by the same scientists who carry on the cruise work, results are not yet available from all cruises. However, a number of important findings have already been announced.

*Vema:* The oceanographic vessel *Vema*, of the Lamont Geological Observatory, Columbia University, made her first IGY cruise, from New York to Recife, Brazil, just prior to the beginning of IGY. The *Vema* then left Piermont, New York, on November 8, 1957 on an Atlantic Cruise to Capetown, South Africa, arriving there on April 7, 1958 (see Fig. 1). This was the first half of an extended cruise expected to end in September 1958. The cruise was planned to include the Scotia Sea, east of the lower end of South America, the Indian Ocean, and the Red and Mediterranean Seas. During the South Atlantic portion of the cruise, cooperative operations were conducted with Brazilian and Argentine vessels.

Objectives were to obtain a more complete understanding of the geologic structure of the continental shelves and the ocean basins, to study the large-scale circulation of ocean waters, and to investigate the nature of sediments on the ocean floor.

In addition to standard oceanographic instruments, the *Vema* is using a new nuclear precision magnetometer, new equipment for study of the $CO_2$ content of the atmosphere and the ocean on a continuing basis, and an underwater camera capable of taking some 70 exposures, permitting correlation with bottom data gathered by other methods.

To study the geologic structure beneath the ocean floor and the continental shelves, seismic refraction measurements are made by two ships working together. The Bra-

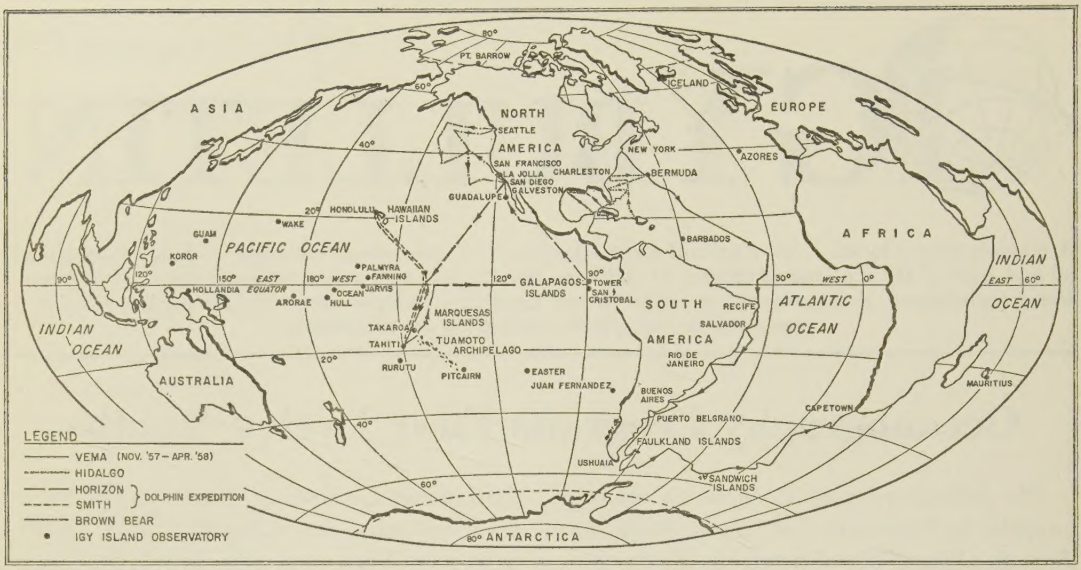


Fig. 1. *Tracks of 1958 IGY Oceanographic Cruises, and Locations of IGY Island Observatories*

Table 1. Types and Number of *Vema* Observations

| *Program* | *No. of Observations* |
|---|---|
| Standard hydrographic stations | 43 |
| Oxygen samples | 956 |
| Salinity samples | 986 |
| Reversing thermometer water temperature determinations | 956 |
| Carbon-14 samples | 52 |
| Tritium samples | 57 |
| Underwater camera stations | 40 |
| Sediment cores | 72 |
| Seismic refraction profiles | 115 |
| Reversed | 15 |
| End-on | 100 |
| Plankton hauls (horizontal) | 70 |
| Vertical biological hauls | 75 |
| Bottom biological trawls | 38 |
| Bathythermographic observations | 1275 |
| Sub-bottom depth recorder track (nautical miles) | 900 |
| Precision depth recorder track (nautical miles) | 18,000 |
| Magnetometer observations (nautical miles of track) | 16,900 |
| Carbon Dioxide measurements | |
| Nautical miles of continuous observations | 18,000 |
| Number of single samples run | 150 |

zilian vessel *Forte de Quimbia* and the Argentine vessel *Sanaviron* cooperated with the *Vema* in the occupation of seismic stations along the continental shelf of South America and in adjacent waters. The geologic structure beneath bays and several estuaries was studied using a sub-bottom depth recorder, a new instrument similar to the echo sounder.

Table 1 provides a count of observations of different types made by the *Vema* on this first portion of the cruise.

*Crawford:* The research vessel *Crawford*, of the Woods Hole Oceanographic Institution, has added several Atlantic sections to its earlier work, completed in the pre-IGY period (see *Bulletin No. 2*). In addition, it conducted some significant studies in the Caribbean Sea.

The *Crawford's* observations will be com-

pared and correlated with similar data obtained by the Woods Hole research vessel *Atlantis* 30 years ago in the hope that this will shed new light on the circulation of the Atlantic Ocean. Efforts will be made to determine the age of the water in the enclosed Caribbean Basin. Of particular importance is knowledge of the depths of sills—submarine ridges separating partially closed basins from one another, or from the adjacent ocean, and blocking exchange of deep water.

During the *Crawford's* cruise, some basins were found in which the deep water is isolated from both North Atlantic and Caribbean deep waters. Moreover, the characteristics of this isolated water suggest that it is residual from previous ocean circulation patterns that existed under different climatic conditions.

The water samples collected on the cruise, along 10 transverse Atlantic sections, provide for the first time adequate information about the distribution of organic and inorganic phosphorous in the sea. On the basis of this information, the Woods Hole scientists now believe that plankton productivity in the open sea may be twice previous estimates.

*Hidalgo:* The research vessel *Hidalgo*, of Texas Agricultural and Mechanical College, is now carrying out an IGY oceanographic cruise in the Atlantic, Caribbean, and Gulf of Mexico (Fig. 1). This cruise is intended to tie into Lamont and Woods Hole cruises to help fill gaps in our knowledge of the oceans to the south and southeast of the United States.

*Atlantis:* The *Atlantis*, of Woods Hole, left late in April of this year for the Indian Ocean, via the Mediterranean and Red Seas. She met the *Vema* of Lamont Geological Observatory in the Indian Ocean, where the two ships conducted seismic operations to study the sub-oceanic crust and made standard oceanographic observations. They then made traverses of the Red Sea, which had never before been studied in this manner. The floor of the Red Sea is thought to consist of a gigantic rift; in the Red Sea itself, deep water of very high salinity has been observed. In July, the ships worked in the Mediterranean Sea, returning to the United States in late summer through the Atlantic.

*Brown Bear:* In the summer of 1957, the University of Washington research vessel *Brown Bear*, made a cruise in the Northeast Pacific (see *Bulletin No. 9*). A unique feature of the University of Washington program was the conversion of data to punch cards while still aboard ship.

A second IGY cruise of the *Brown Bear* got under way on June 30, 1958. The region under study was the eastern Pacific between about 32° and 50°N, and as far west as about 146°W (Fig. 1). The cruise plan included reoccupation of stations occupied 30 years ago by the *Carnegie*, of the Carnegie Institution of Washington, for comparison of present-day data with that obtained by the *Carnegie*. The ship returned to Seattle, its home port, on August 24.

A special objective of the cruise was to determine the location of the transition zone between the subarctic and central regions of the northeastern Pacific. As on the 1957 cruise, data were transferred to punch cards aboard ship.

*Downwind Expedition:* The *Horizon* and *Baird*, research vessels of the Scripps Institution of Oceanography, University of California, completed a five-month expedition in the Southeast Pacific—the "Downwind Expedition"—in February 1958. *Bulletin No. 7, January 1958*, describes the aims of the expedition, techniques used, and results of the first few weeks' work. From this information and from data collected on the remainder of the expedition some preliminary conclusions are possible.

There are indications that North Pacific deep water extends to the Tuamotu ridge, a projection of the East Pacific rise. South of the Tuamotu ridge, the deep water is of Antarctic origin.

It was found that in regions of uplift of the earth's crust beneath the oceans, such as

the Easter Island Rise (the Albatross Plateau), the heat flow in bottom materials was larger than normal. Near regions of severe downwarping of the crust, in the vicinity of the South American Trench along the western edge of the continent, for example, the values were much lower than expected. These findings support the theory that great convection currents exist within the earth's mantle—the layer directly beneath the crust. These currents are believed to carry hot material upward toward the base of the crust in regions of uplift and cooled material downward toward the core of the earth in regions of downwarp. Such convection currents may actually be the cause of the uplifts (plateaus) and downwarps (trenches).

There was considerable variation of crustal thickness beneath seismic stations occupied on the cruise. A basin just east of the Easter Island Rise had one of the thinnest crusts yet found—2 km, or less than half the normal sub-oceanic crustal thickness. Beneath Nasca Ridge, on the other hand, at an average depth of 1600 fathoms, one of the greatest sub-oceanic crustal thicknesses was discovered—perhaps as much as 15 km.

Preliminary analysis aboard ship of some of the seismic data gathered in the equatorial zone of carbonate bottom sediments confirmed previous observations that this sedimentary layer is about twice the mean oceanic sediment thickness of a few hundred meters. Bottom sediment thicknesses observed during the Southeast Pacific part of the cruise, on the other hand, were no greater than normal thicknesses in the Central and North Pacific. At nearly all stations occupied on the cruise, a "second layer" was found between the unconsolidated sediment and the principal crustal layer. Its thickness is generally about 1 km, although in some places it is several km thick.

Ionium/thorium ratios at various depths in the ocean-bottom sediments indicate that the rate of accumulation of these sediments can be measured in millimeters over thousands of years.

One unusual finding was the discovery of an extensive area in which the sea floor is covered with a loose layer of nodules having rich concentrations of manganese, copper, cobalt, and nickel.

*Dolphin Expedition:* In the spring of 1958, the research vessels *Horizon*, of Scripps, and *Hugh M. Smith*, of the Pacific Oceanic Fishery Investigations, US Fish and Wildlife Service, completed a two-months' cruise in the Equatorial Pacific (Fig. 1). The cruise, called the "Dolphin Expedition," explored the Cromwell Current which runs counter to the South Equatorial Current some hundreds of feet beneath it.

This eastward-flowing countercurrent, first discovered at 150°W in 1952, has now been traced for about 3500 mi. Although the origin and westward extent of this current are still unknown, the Dolphin Expedition has established that it disappears at the Galapagos Islands. The countercurrent is about 250 mi wide and has a speed of approximately 3.5 mph; this is more than 2 mph faster than the South Equatorial Current, which flows westward above it. Expedition members first located the countercurrent 100 ft beneath the surface. Its core lay about 300 ft below the surface, becoming shallower eastward, and its total thickness was found to be about 700 ft. This countercurrent transports a volume of water approximately equal to that moved by the Gulf Stream where it emerges from the Straits of Florida. It is thought that this great countercurrent may be an important refertilization mechanism, contributing to the unusual abundance of marine life in this part of the equatorial Pacific.

Beneath this swift, eastward-flowing countercurrent still another current—a weak one, flowing westward—was found. Thus, in the upper few thousand feet of this part of the Pacific there are three ribbon-like currents, lying one on top of another and flowing in opposite directions.

*Antarctic:* The logistic support afforded the IGY Antarctic Program by US Navy Task Force 43 presented an opportunity for limited oceanographic studies in Antarctic

waters by scientists aboard Navy and Coast Guard icebreakers.

Detailed temperature profiles of the Antarctic Convergence have been largely lacking in the past. (The Antarctic Convergence is the zone in which the cold waters of the Antarctic Current sink beneath, and to some extent mix with, the warmer waters of the West Wind Drift.) Hence, special emphasis was placed on such work during the cruises and new information was gathered on the geographic location of the Convergence. In the Indian Ocean sector, the Antarctic Convergence was identified in the vicinity of 55°S. Crossings in the Atlantic sector located it near 56°S, 55°W and near 52°S, 38°W. In the vicinity of the International Date Line, in the Pacific sector, the Convergence was found near 62°S.

Because icebreakers are now able to penetrate deeply into ice-locked Antarctic regions, they have obtained oceanographic data in places hitherto inaccessible and at times during which scientific field study was formerly impossible. Stations in the Weddell Sea in 1956–57 indicate that there is very little change of density with depth. Across the head of the Sea, on the continental shelf, the water temperature was uniformly slightly above −2.0°C from a depth of 100 m to 600 m. Air temperatures ranged from −2.8°C to −6.2°C. Therefore, although it was less than a month past Antarctic midsummer (January 11–20), the sea was losing heat to the atmosphere, and winter cooling had already begun.

Weddell Sea studies verify the theory that Antarctic bottom water is formed by a mixing of the cold, heavy surface water—originating on the continental shelf by winter cooling and freezing—with the warmer circumpolar subsurface water.

In the Ross Sea, one of the highest densities ever met in the ocean—28.14 (gm/liter above 1 kg)—was obtained at a depth of 515 m, only 5 m above the bottom. This suggests the existence at that location of a basin in which very dense water is trapped.

Oceanographic stations were reoccupied

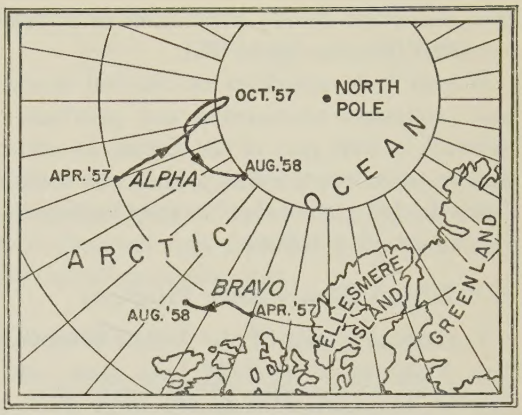


Fig. 2. *Tracks of IGY Drifting Stations Alpha and Bravo Since Their Occupation.*

periodically over several months' time near IGY Little America Station and near Hut Point, in McMurdo Sound. At both places there was a rapid summer decrease in salinity, apparently reflecting melting of the pack and shelf ice; warming of the sea was confined to the upper layers. During the winter, cold brines sinking from beneath the thickening pack ice raise the salinity of the waters over the continental shelf.

Marked differences between the regimes of the waters near Hut Point and near Little America Station are probably caused mainly by the difference in the thickness of the ice bodies near these waters. In the vicinity of Hut Point the ice barrier is relatively thin compared to the 250-m thickness of the Ross Ice Shelf near Little America.

*Drifting Stations:* In the Arctic Ocean, IGY oceanographers pursue their investigations from stations on the drifting pack ice (Fig. 2). This and other Arctic Basin work and some of the results obtained were reported in *Bulletins Nos. 1, 2, 4, 6, 8, 9,* and *12.*

Further results are continually being made available: Hydrographic observations made at Drifting Station Alpha show a uniform temperature of −1.7°C (+29.0°F) from the surface to a depth of 900 ft. Micrometeorological observations indicate that this value has remained constant for a considerable length of time. Regular plankton hauls indi-

cate continued sparse population of phytoplankton (floating plant life).

Woods Hole scientists on Station Alpha have collected crustaceans not previously reported in that part of the Arctic. In addition, a water-worn coral pebble was found in the dredging. (Coral grows only in tropical and sub-tropical waters.)

### IGY Island Observatory Program

The primary aim of the Island Observatory Program is to study both long- and short-period variations of sea level during the IGY. A number of other phases of oceanographic work are included. Sea-atmosphere relationships receive particular emphasis (see *Bulletins 2, 4, 6,* and *9*).

In the Pacific, the Island Observatory Program is directed by the Scripps Institution of Oceanography. The Atlantic program is directed by the Lamont Geological Observatory. Many other US agencies and individuals are contributing directly to the work, and Iceland, Chile, Ecuador, France, Great Britain, Portugal, and Mexico are cooperating in joint projects. United States agencies assisting in the program are the Coast and Geodetic Survey, Weather Bureau, Navy, and Fish and Wildlife Service.

Analysis of data gathered at Pacific observatories (Fig. 1) has yielded the following results, among others:

*Long-Period Waves and Local Weather:* Qualitative study of the daily background at the long-period wave stations indicates that local weather is directly related to the amplitude of sea swell and surfbeat. Short trains of long-period waves (10–90 min) occur daily. Marcus Island records show several occasions during which local squalls passing over or near the island produced sea-level changes that quantitatively corresponded to variations in barometric pressure.

*Hurricane Waves:* Four hurricanes occurred during the period November 1957–April 1958; the waves from each were recorded at one or more stations. The first wave arrivals consisted of long undulations of sea level with periods of 10–20 min. These were followed by great intensification of the surfbeat and the sea swell. The entire process from normal to peak activity occurred within three hours at stations within 200 mi of the disturbance. At distant stations, as much as 24 hours elapsed between the long-period forerunners and the swell.

*Tsunamis:* A statistical study of inundation heights from tsunamis (so-called tidal waves resulting from submarine earthquakes, landslides, or volcanic action) around the Hawaiian Islands is in progress. The study indicates that the local height of on-shore waves on a nearly circular island can be adequately represented by a simple empirical equation. Using this equation, an apparent inverse relationship was found between the individual wave heights and the offshore slope. In all cases, the distance from crest to crest at the beginning of the slope was of the order of magnitude of the island diameter.

*Hemispheric Water Exchange:* Tide-gauge data from both oceans show a change in mean sea level from summer to winter. Most of this appears to be related to expansion and contraction of water with seasonal temperature changes, but it may also be due to movement of water between northern and southern hemispheres.

### Carbon-Dioxide and Radiochemistry Studies

*Carbon Dioxide:* A coordinated effort is being made by scientists at Scripps, Woods Hole, Lamont, the University of Washington, and Texas A & M to gain an understanding of the $CO_2$ content of the atmosphere and oceans.

Man, in his burning of fossil fuels and denudation of the land's surface, may be performing a gigantic geophysical experiment in which the $CO_2$ cycle is being influenced. It is thought we may be increasing the $CO_2$ input into the atmosphere by 70% in 40 years, although it is not certain how much of this may be absorbed by the oceans. A substantial increase in $CO_2$ content in the

Table 2. Radiochemical Analyses

| *Woods Hole* | *Scripps* | *Lamont* | *Texas A & M* | *U. of Wash.* |
|---|---|---|---|---|
| $H^3$, $C^{14}$, $Sr^{90}$, $Sb^{125}$, $Cs^{137}$, $Ce^{144}$, $Pm^{147}$ | $H^3$, $C^{14}$, $S^{89}$, $Sr^{90}$ | $H^3$, $C^{14}$ | $C^{14}$ | $C^{14}$ |

air would trap more of the earth's radiated heat and cause a warming of temperatures.

Data collected during the IGY will be needed for comparison with measurements made 15 to 25 years from now to determine whether the $CO_2$ content is changing. It is now possible, owing to availability of a gas analyzer capable of a precision of $\frac{1}{10}$ part per million (ppm), to achieve the accuracy required for such determinations.

Atmospheric $CO_2$ measurements made on the Downwind Expedition indicated a very slight but distinct latitudinal variation. Its range was about 3–4 ppm. In general, it was found that $CO_2$ tension in the sea water, that is, the part of the total pressure caused by $CO_2$, exceeded that in the atmosphere. An observation near the Chilean coast showed extraordinarily high $CO_2$ tension, apparently the result of upwelling of the deep water.

Results of IGY investigations thus far indicate a remarkable constancy of $CO_2$ content in the atmosphere. At IGY Little America Station, Antarctica, the variation during a period of more than one year was only 0.3%. Continuous measurements over a period of two months at Mauna Loa Observatory, Hawaii, showed a variation of 1.0%. Measurements made continuously aboard research vessels in the Pacific between the Bering Sea and Valparaiso, Chile, in 1957, show a variation of 2.0%. The mean values for all of these locations lie very close together. Air samples collected in the Gulf of Alaska and at Cape Hatteras in April 1958 also yielded concentrations of $CO_2$ whose mean values were very close to those obtained at the above locations.

*Radiochemistry:* Those institutions carrying out the $CO_2$ program are also performing radiochemical analyses of sea water. Such analyses are used to determine the circulation of the oceans and the age of sea water at various levels. Table 2 lists the kinds of radiochemical analyses being made at the participating institutions.

## Future Plans

The international cooperation which is such an integral part of the IGY has had a profound impact on oceanographers. As a result, the International Council of Scientific Unions (ICSU) has organized a Special Committee on Oceanographic Research (SCOR) to foster similar cooperative programs in the future. Several meetings of SCOR have already been held, and plans have been made for a long program of oceanographic research in the Indian Ocean, about which little is now known. In the course of this work, encouragement and training will be given to scientific talent in bordering countries. Similar work will eventually be performed elsewhere.

The National Academy of Sciences has also recognized the need for long-range planning in oceanography, and has organized a new Committee on Oceanography, under the chairmanship of Harrison Brown, California Institute of Technology. The Academy's Committee contains several panels to study specific questions, such as design of oceanographic research vessels, new devices to explore the oceans, and marine resources. The Academy's Committee will carry out liaison with SCOR.

The planning of both SCOR and the Committee on Oceanography carries far beyond the specialized IGY program in oceanography. Included are marine biological studies, with emphasis on fisheries and food production in the sea, and concerted attacks on hitherto little studied regions.

# Ionospheric Electron-Density—Height Profiles

*Material for this report was furnished by E. R. Schmerling of Pennsylvania State University.*

For many years a large number of stations, widely dispersed over the world, have been sounding the ionosphere—the electrically charged region of the atmosphere which reflects radio waves—and recording the results. The most widely used method is to send pulsed radio signals vertically upward. The time-delay of the echo of each pulse from the ionosphere is shown on an oscilloscope. A photographic record of the oscilloscope trace relates the heights of the echoes to the different radio frequencies used. Such a record is called an ionogram.

Customarily, only several easily-obtained descriptive characteristics of the ionosphere are obtained from the ionograms. Use of these characteristics in the prediction of the most suitable radio frequencies for communication purposes has been outstandingly successful. The values obtained from ionograms are regularly published by national organizations—in the United States, for example, by the Central Radio Propagation Laboratory (CRPL) of the National Bureau of Standards.

## Measurement of Ionograms

Ionograms show the virtual heights of reflection of radio pulses of different frequencies. The virtual height, by definition, is the time between the transmission of a pulse and its return, multiplied by half the velocity of light in free space. Since radio pulses do not travel in the ionosphere with this velocity, the virtual height is generally very different from the true height of reflection.

Reflection is due to the presence of free electrons in the ionosphere; at the reflection point, the electron density is related to the radio frequency of the reflected pulse. If the true height of reflection can be found from the ionogram, the ionogram will provide a profile of electron density at different heights. Such profiles give a very detailed picture of the ionosphere. They are of great value to the radio physicist, for with more precise knowledge of how the ionosphere behaves, he can better formulate and test theories of its origin and character.

The processes which affect the electron densities in the ionosphere can be classified as electron-production (mainly resulting from solar radiation), electron-loss (recombination and molecular attachment) and electron-drift (owing to winds of tidal and electrodynamic origin). These processes are imperfectly understood.

Most previous work has been based on the critical frequencies (the maximum frequency reflected by a given ionospheric layer) and on the minimum virtual heights of the various ionospheric strata, or layers. These are easily measured from the ionograms, but give very incomplete information. The critical frequencies give electron densities at the peak densities of the layers but do not specify their heights. The minimum virtual heights are of uncertain significance as they are determined as much by the underlying ionization as by the true lower boundaries of the layers. Since the production, loss, and drift rates are extremely dependent on height, and since considerable movement of the layers takes place, the height specification is of great importance.

## Electron-Density Profiles

The reduction of ionograms to electron-density profiles is mathematically a complicated problem. It is like deducing the contour of a hill from observations of the time needed for a ball, after one push, to roll up one side and down again. As far back as 1930, the physicist de Groot showed that the two problems are formally identical if the effect of the earth's magnetic field is neglected. If the effect of the earth's mag-

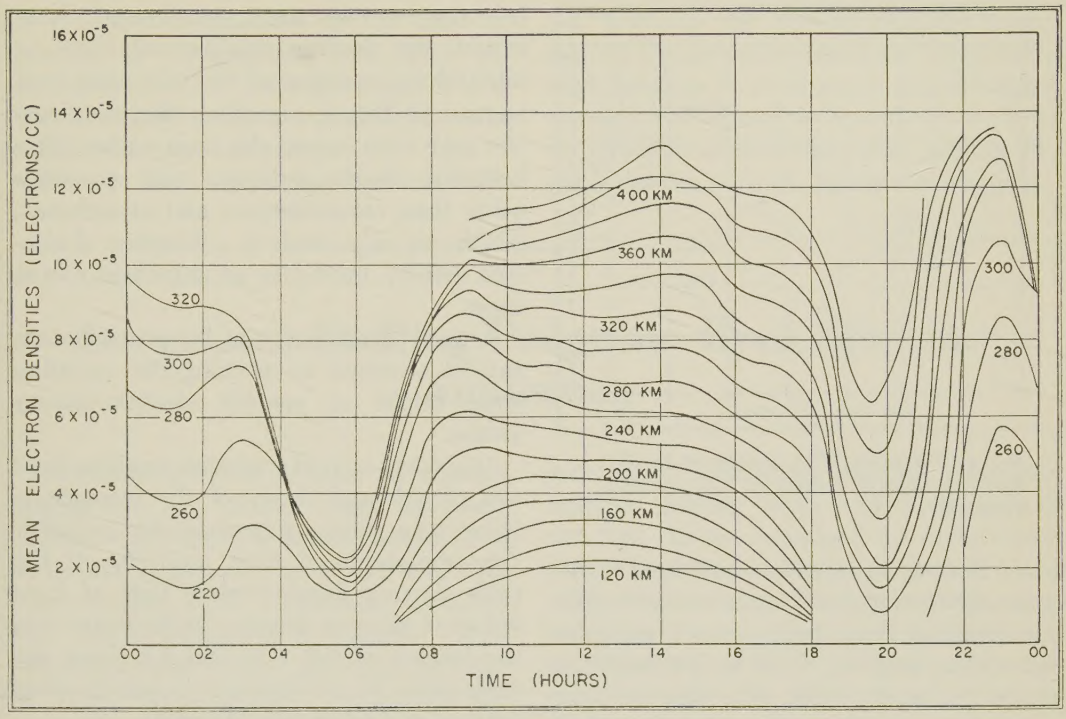


Fig. 3. *Daily Mean Electron Densities at Talara, Peru, During July 1957*

netic field is included, the problem is even more complicated.

Important work has been done by J. M. Kelso, who, while at Pennsylvania State University, devised a rapid but approximate method of solution. Several more precise methods of solution are now available. A matrix method devised by the British scientist K. G. Budden (1955) includes the effect of the earth's magnetic field and determines the profile without making assumptions concerning the profile shape; it is assumed, however, that the electron concentration does not decrease with altitude. (This condition does not usually hold everywhere in the ionosphere, but the assumption can be assessed in using the method, and is generally found to be of minor importance.)

## IGY Program

During the IGY, data-reduction programs have been set up in England and the United States. The two programs give reasonable global coverage and lay the foundations for a world-wide survey. For the US program, under the supervision of E. R. Schmerling ionograms are being selected from the following four stations: Washington, D. C.; Talara, Peru; Canal Zone; and Huancayo, Peru. Records are reduced at the Pennsylvania State University for every hour of the three Regular World Days and the 10 magnetically quietest days of each month. This is actually a very small selection from the available data. However, the program is a minimum one aimed at determining electron density behavior so that ionospheric theories may be formulated and tested. Recently, another program of reduction of ionograms for true heights was initiated at CRPL, in Boulder, Colorado. It is directed toward providing electron-density profiles of the ionosphere at locations where radio signals from satellites are observed after propagation through the ionosphere.

"Forty-by-forty matrices" have been developed at Pennsylvania State University for the reduction process. These matrices are arrays of the numerical coefficients con-

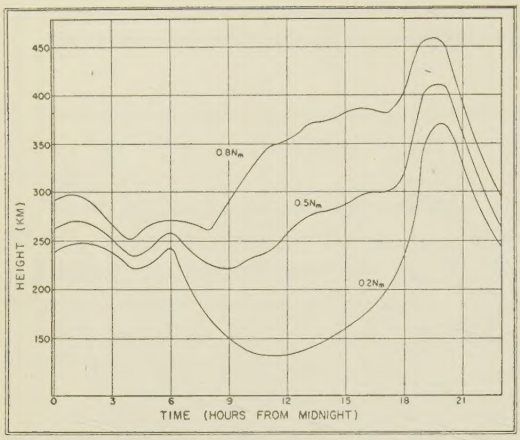


Fig. 4. *Variation With Height of Specific Electron-Density Values at Talara, Peru, July 1957.*

tained in forty equations to be solved simultaneously for forty unknown variables (the true heights) from forty known variables (the virtual heights). Used in the reduction process for each station is a characteristic matrix that depends on the magnetic field at that location. Development of the matrices is being carried out on the University's digital computer, PENNSTAC. Measurement of the virtual height of the ionograms at specific frequencies by scaling is performed manually in 10–15 minutes per record; the computer then performs the reduction in approximately one minute, and prints out true-height values for specified values of electron density.

**Preliminary Results**

For survey purposes, it is useful to average out some of the day-to-day fluctuations. This can be done conveniently by reading off the electron densities from the profiles at 20-km height intervals, and averaging these over all of the days in each month. The mean curve for Talara produced in this way for July 1957 is illustrated in Figure 3. These curves have several features in common, but they also show some striking differences. Near sunrise, the electron densities increase rather rapidly at all heights, as would be expected. At night, however, the behavior becomes more complicated. Near sunset, the electron densities all show an initial drop, as expected, but thereafter tend to rise. At Talara, nighttime electron densities may even exceed the noon values. This behavior clearly indicates that processes other than recombination and attachment, which can only result in a decrease of electron density, must play an important role at night.

A good visualization of layer movements can be obtained by plotting the variation with height of specific electron-density values.

(In order to avoid confusion resulting from the growth and decay of the ionospheric layers as a whole, it is preferable to follow the movements of fixed multiples of the peak electron density rather than of fixed values of electron density. To illustrate this, the heights of 0.8, 0.5, and 0.2 times the peak value, $N_m$, at Talara have been graphed with respect to time in Figure 4).

The mean curves that result characterize the height movements, and their spacing provides a measure of the thickness of the ionospheric layer. It is seen that the bulk of the ionosphere is lower by day than at night. An empirical explanation of the nighttime increase of electron density is also immediately apparent, since the thickness decreases markedly. The nighttime increase is thus due to compression of the ionosphere rather than to a nocturnal source of ionization with a peculiar geographical distribution.

It is pertinent to inquire into the differences of behavior at the four stations. These have been chosen quite close to the 75°W meridian, but with widely different geographic and geomagnetic latitudes. The differences of behavior are, in fact, closely linked with the local magnetic dip, as shown by Sir Edward Appleton of the United Kingdom in 1950 and 1954. A natural explanation is found in terms of electrodynamic movements, since tidal winds acting on charged particles produce electron movements that

are profoundly influenced by the local inclination of the magnetic field. This was pointed out by D. F. Martyn of Australia in 1947. While the details are still obscure, the general effects are fairly clear.

No more than a start has been made on the provision of electron-density—height data on a sufficiently large scale. Much more work remains to be done, but preliminary evaluation of data already available is yielding valuable information and guiding investigators to some of the right questions.

# Deep Core Drilling Program: Byrd Station, Antarctica

*The following report is based on material supplied by J. A. Bender, Chief, Snow and Ice Branch, SIPRE. The drilling program was carried out by glaciologists E. W. Marshall, Project Leader, R. W. Patenaude, and A. C. Gow; Chief Driller was J. B. Tedrow.*

During the summers of 1956 and 1957, the US Army Snow, Ice and Permafrost Research Establishment (SIPRE) conducted drilling operations at its experimental station on the Greenland Ice Cap. (See *Bulletin No. 7, January 1958*). Although the Greenland drillings produced valuable glaciological and climatological data, their primary purpose was to develop techniques for drilling and core removal in ice.

These techniques were used at IGY Byrd Station in the Antarctic during the 1957–58 summer season to obtain 4-inch cores to a depth of 1013 ft. While the hole was not as deep as that drilled in Greenland in 1956, the core samples recovered are formed of snow of much greater age. (The ice at the 1000-ft level at Byrd Station is formed from snow which fell about 1400 years ago. The age of the deepest core from Greenland is about 950 years. The difference follows from the relatively light precipitation in the Antarctic.)

## Drilling Methods

The core drilling at IGY Byrd Station was accomplished with equipment and techniques similar to those employed in coring rock. Major exceptions were the bits, core catchers, drilling fluid, and a specialized core-feed device developed to compensate for the fragility of the ice to be cored.

Previous experience had shown that very low bit pressures are required for drilling in ice. Therefore, all of the drilling and coring was done with the drill string in tension. But the rate of feed became irregular as the weight of the drill string increased with depth. To correct this, a hydraulic core-feed device capable of very fine adjustment was developed, making possible a perfectly constant rate of feed.

In order to prevent the ice from shattering while coring, it was necessary to control the rotation speed of the bit and the rate of penetration within narrow margins and to hold vibration of the core barrel and bit to a minimum. The success of the measures used is shown by the fact that 98% of the core was recovered in usable condition.

Cold compressed air under a pressure of 60 lbs/in$^2$ was used as the drilling fluid. The temperature of the compressed air varied with the temperature of the outside air but was always kept well below freezing. In the permeable upper layers of the snow, the air tended to dissipate into the snow instead of circulating; as a result, the cuttings adhered to the hole wall or fell back down the hole. This difficulty was solved by casing the drill hole to a depth of 115 ft, where the snow was sufficiently impermeable to maintain air circulation.

Table 3. Mean Deep-Core Densities

| *Depth (In meters from surface)* | | *Density (gm/cm³, ± 0.005 cm)* |
|---|---|---|
| 18.50–19.00 | | 0.599 |
| (60.3′) 19.00–20.00 | | 0.606 |
| 20.00–21.00 | | 0.608 |
| 21.00–22.00 | | 0.613 |
| 22.00–23.00 | | 0.619 |
| 23.00–24.00 | | 0.630 |
| 24.00–25.00 | | 0.638 |
| 25.00–26.00 | | 0.643 |
| 26.00–27.00 | | 0.653 |
| 27.00–28.00 | | 0.655 |
| 28.00–29.00 | | 0.660 |
| 29.00–30.00 | | 0.673 |
| 30.00–31.00 | | 0.676 |
| 31.00–32.00 | | 0.684 |
| 32.00–33.00 | | 0.689 |
| 33.00–34.00 | | 0.695 |
| 34.00–35.00 | | 0.699 |
| 35.00–36.00 | | 0.704 |
| 36.00–37.00 | | 0.710 |
| 37.00–38.00 | | 0.715 |
| 38.00–39.00 | | 0.723 |
| 39.00–40.00 | | 0.724 |
| 40.00–41.00 | | 0.732 |
| 41.00–42.00 | | 0.736 |
| 42.00–43.00 | | 0.738 |
| 43.00–44.00 | | 0.746 |
| 44.00–45.00 | | 0.743 |
| 45.00–46.00 | | 0.750 |
| 46.00–47.00 | (150′) | 0.757 |

Table 4. Densities of Spot Samples

| *Depth (Meters)* | | *Density (gm/cm³, ± 0.005 cm)* |
|---|---|---|
| 123.00 | (400′) | 0.885 |
| 150.00 | | 0.890 |
| 173.00 | | 0.895 |
| 200.00 | | 0.899 |
| 222.00 | (721.5′) | 0.905 |

## Analysis of Cores

Close inspection of the early cores revealed a detailed stratigraphic sequence. Alternating layers of coarse- and fine-grained snow were associated with thin ice bands (4 mm) at regular intervals in the cores. Thick bands of ice, indicative of pronounced thaws such as would occur in summer on a temperate zone glacier, were not recognized. However, it is hoped that a detailed density analysis of successive layers in the stratigraphic sequence will permit investigators to distinguish between summer and winter snows and to determine the extent of yearly accumulation.

*Work at Byrd Station:* The ice cores were placed in a trough and viewed from above with the aid of a light source placed under the trough. The exact positions of ice layers were determined by use of a measuring tape laid along one edge of the trough. The nature of the layers (whether coarse, fine, or icy) was also recorded. Successive sections of the core were then photographed. This combined stratigraphic-photographic procedure was begun on cores taken from the 60.3-ft (18.36-m) level and continued on cores down to the 319.5-ft (97.38-m) level. The photographs were mounted in order on cardboard sheets to give a running stratigraphic column through this interval. Distinctive layering could be observed in cores from depths down to 400 ft. Below this, the cores were homogeneous and visible stratification disappeared, with the exception of the thin ice bands; these persisted to the bottom of the drill hole.

Determinations of the density of individual layers were started using cores from the 60.3-ft level (18.36-m) and completed to 154.4 ft (47.06-m). These determinations were made in the time available at IGY Byrd Station. In all, densities were calculated for 700 core segments ranging in length from 15 cm to slightly less than 1 cm.

Mean densities of 1-m increments have also been calculated; these are presented in Table 3. Densities were also determined for spot samples selected at depths of 123 m, 150 m, 173 m, 200 m, and 222 m (Table 4). The density of the sample from the 222-m depth approaches the maximum value for ice, 0.917. Thin sections were made from the same samples and examined under the microscope for grain-size differences. There was insufficient time to carry out detailed fabric studies of the thin sections while at Byrd Station.

The core from a 3-in, hand-augered hole sunk to a depth of 71 ft (21.6 m) was similarly treated. Densities from 176 segments were determined for the first 30 ft and mean densities for 1-m increments were calculated (see Table 5).

*Work at SIPRE:* At the outset of drilling

Table 5. Mean Densities of Hand-Augered Cores

| *Depth (In meters from surface)* | *Density ($gm/cm^3$, ± 0 .005 cm)* |
|---|---|
| 2.32–3.00 | 0.449 |
| 3.00–4.00 | 0.405 |
| 4.00–5.00 | 0.421 |
| 5.00–6.00 | 0.432 |
| 6.00–7.00 | 0.487 |
| 7.00–8.00 | 0.515 |
| 8.00–9.00 | 0.526 |
| 9.00–9.37 | 0.536 |

at IGY Byrd Station it was intended to split the 4-in cores lengthwise. One half was to be returned to SIPRE, at Wilmette, Illinois, for further research and the other half was to be retained at Byrd Station for use in further studies in the Antarctic. However, because of the large amount of detailed stratigraphy in cores from depths down to 400 ft, it was decided to keep cores from this section of the drill hole in their original state. Splitting of cores from the lower 600 ft was begun, but because of failure of the band saw, cores from the lowest 160 ft remained uncut. Both of the uncut core sections, half the longitudinally split cores, cores from the 71-ft auger hole, and cores from two shallower holes at IGY Byrd Station were transported from the Antarctic aboard the USS *Glacier*. The cores were maintained at 0°F throughout the trip to Boston, where they were unloaded and transported by refrigerated truck to the SIPRE laboratories at Wilmette.

Further research at Wilmette will include the completion of the density profile, grain-size and petrofabric studies, analysis of enclosed foreign particles, measurement of gas-bubble pressure, chemical analysis of entrapped gas, and measurement of tritium and other radioactive substances. Measurement of the ratios of oxygen isotopes 16 and 18 will be carried out at the California Intitute of Technology.

Table 6. Drill-Hole Temperatures

| *Depth* | *Average Temperature (°C. ± 0.10)* |
|---|---|
| 50′ | −27.92 |
| 100′ | −27.95 |
| 150′ | −27.98 |
| 200′ | −28.14 |
| 250′ | −28.26 |
| 300′ | −28.29 |
| 350′ | −28.31 |
| 400′ | −28.39 |
| 450′ | −28.42 |
| 500′ | −28.40 |
| 550′ | −28.40 |
| 600′ | −28.46 |
| 650′ | −28.46 |
| 700′ | −28.51 |
| 750′ | −28.52 |
| 800′ | −28.52 |
| 850′ | −28.53 |
| 900′ | −28.55 |
| 950′ | −28.59 |
| 1000′ | −28.59 |

Note: Temperatures continue to decrease with depth.

## Temperature Measurements

Temperature measurements were made in the deep drill hole to a depth of 1000 ft (Table 6) using a 100-ohm thermohm and a Wheatstone bridge temperature indicator.

Thermal conditions in the hole were disturbed by the drilling and by the cold compressed air used as the drilling medium. Therefore, temperature measurements were not begun until three days after completion of the drilling. This allowed the hole to return to thermal equilibrium.

The thermohm was read at 50-ft intervals. It was given a minimum of two hours at each level to come to equilibrium. Instrument errors, reading errors, and the disturbed thermal conditions from the effects of drilling permit an accuracy of ±0.10°C.

Because steel casing was set to a depth of 115 ft, temperatures taken within this upper zone may be subject to errors greater than ±0.10°C.

# Progress of the Moonwatch Program

*Material for this report was furnished by Leon Campbell, Jr., and Armand Spitz of the Smithsonian Astrophysical Observatory.*

Plans for optical tracking of IGY artificial satellites, under the direction of the Smithsonian Astrophysical Observatory, anticipated two phases. Immediately after a launching, the Moonwatch teams of the volunteer visual observation program, using low-power, wide-field telescopes, would search for the satellite. Once the satellite had been located, or "acquired," and its orbit computed, optical tracking would be carried on by the large tracking cameras (see "Optical Tracking of Earth Satellites," *Bulletin No. 12*). However, when the USSR satellites were launched, Moonwatch teams necessarily carried on the visual tracking program until the full complement of tracking cameras could be put into operation.

A measure of the value of Moonwatch teams in the satellite visual observing program is the number of scientifically useful observations produced. Not only have Moonwatch teams provided a great number of observations but the observations cover all the satellites launched to date. With these data, together with the radio tracking data provided by the Naval Research Laboratory, it has been possible for the Smithsonian Astrophysical Observatory to compute preliminary ephemerides that have been used to position the satellite tracking cameras at the IGY precision tracking stations. Furthermore, Moonwatch observations provided almost daily have been utilized in the constant refining of these ephemerides.

## Results

There are approximately 230 Moonwatch stations in various parts of the world. Eighty per cent of these stations have contributed observational data. Many of the stations that have not made observations are among those recently organized.

Through May 9, 1958, observations of scientific value have been reported by 181 teams. In these observations, the positional data were accurate to one degree of arc, the time of observation accurate to one second, and the objects under observation were identifiable as satellites or as orbiting parts of the launching vehicles. The stations made either one observation or a group of observations during a single satellite crossing on 1599 occasions.

The following table shows the total observing occasions, or sessions, credited to teams in the indicated areas of the world:

| *Area* | *1957α* | *1957β* | *1958α* | *1958β* | *1958γ* | *Total* |
|---|---|---|---|---|---|---|
| U.S. | 278 | 523 | 60 | 8 | 18 | 887 |
| Japan | 134 | 348 | 6 | 4 | — | 492 |
| Africa | 23 | 52 | 41 | 2 | 8 | 126 |
| Australia | 31 | 36 | 3 | 2 | — | 72 |
| Elsewhere | 3 | 18 | 1 | — | — | 22 |
| | 469 | 977 | 111 | 16 | 26 | 1599 |

At these observing sessions, the following numbers of separate observations were made: teams in the United States, 2013; Japan, 879; Africa, 256; Asia, 21; Australia, 259; South America, 11; Central America, 4; total 3443.

Throughout the period of visual tracking, Moonwatch observational reports have usually furnished data in a sufficiently constant flow to allow for continual refining of preliminary ephemerides of the several objects in orbit. The world-wide distribution of Moonwatch stations has made this possible; as the visibility areas have shifted around the world, there have generally been teams so located as to be able to continue to observe the satellites.

During the early months of the program, reports from United States teams were received by telephone at the Smithsonian Observatory within a few minutes of the actual observations. Recently, telephone reporting has been discontinued in favor of telegraph. The results, with respect to accuracy and speed of transmissions, compare most favor-

ably. Moreover, telegraphic reporting has allowed conservation of the limited manpower at Moonwatch headquarters. Reports from stations outside continental United States have been transmitted, from the beginning of satellite observing, over commercial cable and over IGY and other communication systems. These facilities, too, have proved satisfactory.

Several days before the demise of 1957$\beta$, all Moonwatch teams were called upon to set up groups of 4 or 5 observers each to watch throughout the darkness hours of April 12, 13, and 14, 1958, for its fall. Observations of the satellite were made by the three teams toward the very end of the satellite's last revolution. These reports were as follows: Millbrook, N. Y., on April $14^d01^h45^m35^s$; Bryn Athyn, Pa., $01^h45^m46^s$, and New Haven, Conn., $01^h45^m47^s$, (UT). Within a few minutes of these observations, approximately 15 sightings were made of the dying satellite by ships at sea in the Caribbean, and by thousands of persons on islands in the area. Exactly where the satellite and its fragments fell is not determined, but it was last observed over the sea off the coast of the Guianas.

### Future of Program

Continued interest in visual observation of satellites is gratifying because of the great deal of observing that undoubtedly lies ahead. Satellite radios may fail before preliminary ephemerides are determined, and observations will need to be made of the dying moments of satellites. Also, each launching may produce not only a radio-signalling satellite, but one or more orbiting components without radios. To date, there have actually been more objects in orbit without radio transmitters than with them.

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